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On a crystal of augelite from California.

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Augelite was originally described from Sweden by Blomstrand (1868) who obtained the composition $2Al_2O_3.P_2O_5.3H_2O$ from a massive mineral with cleavage in three directions. No further description of this inadequately defined mineral appeared until Prior and Spencer (1895) gave their complete and exact characterization of well-crystallized material from Machacamarca, department Potosi, Bolivia, supplemented by observations by Spencer (1898, 1907) on further finds at Tatasi, department Potosi, and at Oruro, Bolivia.

Lemmon (1935) first recognized augelite as cleavage masses in the commercial deposit of andalusite at White Mountain, Mono County, California, and gave determinative observations which established the identity of the mineral. In this locality Kerr (1932) had noted corundum, diaspore, pyrophyllite, alunite, lazulite, and rutile, associated with the andalusite. In addition to these minerals Professor Joseph Murdoch of the University of California at Los Angeles, has found small, white, tabular crystals of apatite in a specimen carrying augelite.[1] Crystals of augelite from this deposit, with a number of new forms, were mentioned by Pough (1936) in an inconspicuous notice which we did not see until our work was nearly done.[2]

[1] Personal communication, March 22, 1941.

[2] In answer to an inquiry Dr. Pough kindly sent us the draft of an unpublished description of the crystals, with permission to use his observations. Since Dr. Pough may find a future occasion to add to the morphology of augelite we will not

In a collection of uncut stones belonging to Mr. G. G. Waite of Toronto one of us noticed a large, clear, well-developed crystal described as augelite from White Mountain, California. Mr. Waite kindly placed this crystal at our disposal before condemning it to the lapidary's wheel, enabling us to supplement the specific description of augelite with some further observations on the geometrical crystallography and optics and to make X-ray photographs giving the unit cell and powder pattern of the mineral.

Morphology.

Our crystal of augelite measures $15 \times 8 \times 6$ mm. in the directions of the axes *a*, *b*, *c*, respectively. In the conventional position the right side is entirely bounded by faces of good quality meeting in sharp or slightly abraded edges; the left side is formed mainly by an over-developed plane $(1\bar{1}0)$ of the perfect prismatic cleavage. An uneven surface, partly following the more difficult cleavage $(\bar{2}01)$ in our notation, also mars part of the upper-rear surface of the crystal. The drawing (fig. 1) shows the relative development of the larger forms with the left side symmetrically restored.

The crystal was measured on the two-circle goniometer with reference to *b*(010) as the pole-face, and plotted in gnomonic projection for reconsideration of the choice of the geometrical elements. In spite of the large size of most of the faces generally very good reflections were obtained, leading to the identification of most of the forms found by Spencer and a number of additional forms the majority of which, as we subsequently found, had been noted by Pough.

As regards the question of choosing axial ratios the outlook has somewhat changed in recent years. Formerly an acceptable choice was made by taking axial directions exhibiting the full symmetry of the crystal and axial lengths giving the simplest symbols for the cleavage planes and the principal forms. Nowadays it is rather generally agreed that the crystal form should be referred to axial ratios directly comparable to the dimensions of the properly chosen unit cell of the crystal lattice, as given by X-ray measurements. Often well-developed pseudo-symmetry will suggest the choice of a simple multiple lattice cell as the basis of both the geometrical and the structural descriptions. The change to the structural lattice cell usually leads to a definite simplification of the geometrical presentation; occasionally a cleavage receives more compli-

draw on his material, except to mention his two illustrations: one represents a prismatically developed crystal with *a*(100) developed as a large face; the other shows a crystal tabular on *c*(001) with unlike (*hhl*) forms on the right and left sides.

cated indices, as in the classic case of calcite; but never, to our knowledge, is a systematic complication of notation introduced.

This change of outlook has led to renewed interest in the relation of crystal form to crystal structure. A long step towards a solution of this problem was taken by Donnay and his associates (Donnay and Harker, 1937; Donnay, 1938) who have found that the importance (size and frequency) of a crystal face (*hkl*) is in good approximation proportional to the spacing of the structural planes (*hkl*), where the indices (*hkl*) con-

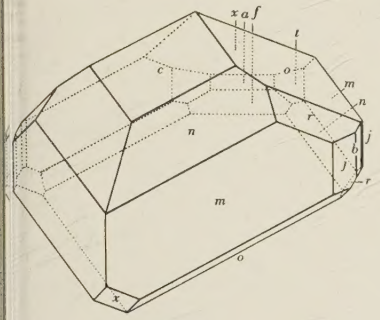

FIG. 1

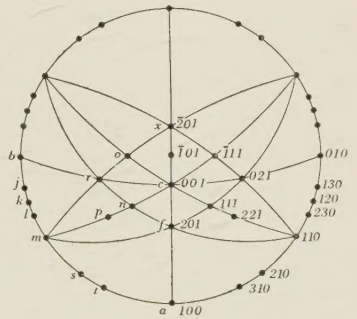

FIG. 2

FIG. 1. Augelite: crystal from California, restored, omitting very small faces.
FIG. 2. Augelite: stereographic projection (structural setting) of the forms observed on a crystal from California.

form to the systematic extinctions of the space-group. This important generalization, which may justly be called Donnay's law, is a generalization of the law of Bravais, which stated that the importance of a crystal plane is proportional to the spacing (or the reticular density) of the corresponding lattice planes, and is therefore affected by the systematic halving (or division by 3) in the centred lattices. Donnay's law recognizes that the importance of forms is further dependent on the additional halving (or division by 3, 4, 6) of the spacings of structural planes (axial planes and planes in special zones) caused by the symmetry of the space-group. As a consequence of Donnay's law the geometrical form of the crystal lattice and the space-group may be inferred from the crystal morphology. Recently this was strikingly shown by Taylor (1940) who correctly predicted the space-group of stephanite from the morphology and then showed, from X-ray measurements in this laboratory, that the previous röntgenographic determinations were inadequate.

In the present case it was interesting, therefore, to seek the crystal

lattice and space-group from the morphology before taking the X-ray photographs. Using an inspective method which relies on the known relative importance of the crystal forms, a measure of interplanar spacings as given by the gnomonic projection, and a knowledge of the possible extinction conditions, we were led unambiguously to the following conclusion: the geometrical equivalent of the structural lattice is obtained by halving the c-axis of Spencer; the morphological extinctions, indicated by systematically subdued form-importance, are ex-

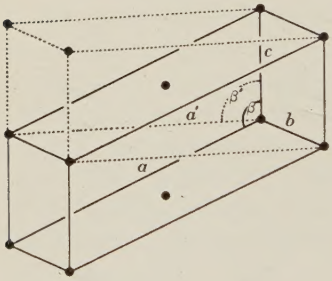

Fig. 3

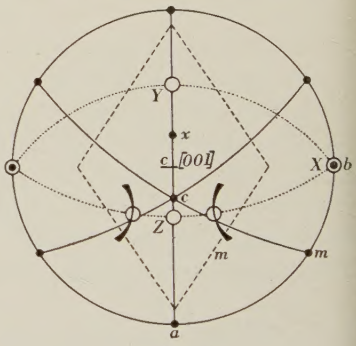

Fig. 4

Fig. 3. Augelite: crystal lattice, showing the adopted base-centred cell (full lines) and the alternative pseudo-orthorhombic body-centred cell (dotted lines).

Fig. 4. Augelite: observed optical orientation.

pressed by the rule: (hkl) present only with $(h+k)$ even; the lattice is therefore base-centred and there is no further space-group condition. Consequently the 'aspect' (Donnay and Harker, 1940) is C^* and the possible space-groups are Cm, $C2$, $C2/m$, according to the crystal class. As shown later the X-ray measurements lead to the same result. On a subsequent occasion Professor Donnay inspected the morphological data and quickly came to the same conclusion.

Since our angular measurements agree closely with the more numerous measurements of Spencer, we have taken Spencer's elements as the basis of the new geometrical values:[1]

$$a:b:c = 1{\cdot}6419:1:0{\cdot}6354;\beta = 112^\circ\,26\tfrac{1}{2}'.$$

Spencer's symbols are correspondingly transformed by halving the last index to give the notation used throughout this paper.

A possible alternative setting deserves brief mention. The lattice we

[1] We prefer to define the monoclinic interaxial angle as the angle between the positive ends of the a- and c-axes, as in the general (triclinic) case, giving the obtuse form of the angle β.

have found might be defined by the nearly rectangular body-centred cell (a' b c β') in fig. 3. This setting would be justified if the crystal habit were clearly pseudo-orthorhombic. It is true that the quasi-symmetrical planes c and x are sometimes nearly equally developed (Spencer, 1895, p. 19), but the typical habit is tabular on c(001) and the distribution of forms (fig. 2) shows pronounced lack of orthorhombic pseudo-symmetry. Since, furthermore, a face-centred monoclinic cell (a b c β) is preferred to a body-centred cell in structural crystallography, the former is indicated in the present case.

The goniometric results are summarized in table I, in which the forms and cleavages marked with an asterisk are new, or provide confirmation of forms previously reported as uncertain or without measurements. The forms observed on the crystal are also shown in the stereographic projection, fig. 2.

Some notes on the new or confirmed forms follow:

j(130). Noted by Pough. Good faces of medium size (fig. 1).
k(120), l(230). New. Minute faces on the edges j/m.
s(210). Noted by Pough. Minute faces on the edge m/t.
t(310). Noted as doubtful by Spencer and observed by Pough. Fair face of medium size between a and m (fig. 1).
p(221). Noted by Pough. Good narrow face on the edge m/n.

The previously recorded cleavages of augelite are (110) perfect, ($\bar{2}$01) good. On our crystal the cleavage (110) is perfect and easy; ($\bar{2}$01) also shows perfect surfaces but is distinctly difficult to develop, as we found when preparing short cleavage prisms for optical and X-ray work. In addition to these cleavages the crystal showed imperfect cleavages (001) and ($\bar{1}$01) giving reflecting steps in good position on the broken part between c and x.

All the forms reported on augelite, by Prior and Spencer (1895), Spencer (1898), Pough (1936), and the present authors, are given in table II, with elements and angles in a standard style for the established forms.[1] In this table we have given the letter q to the form (441), noted as doubtful by Spencer and observed again by Pough.

Since the application of Donnay's law led to the structural lattice and space-group the case of augelite affords confirmation of the law. The verification can be shown more definitely by comparing the sequence of

[1] A number of Spencer's calculated angles (1895) compare directly with calculated angles in our table; these show the expected agreement except for three angles, $ao = 31° 07\frac{1}{2}'$, $an = 54° 53'$, $co = 39° 11\frac{1}{2}'$ (Spencer), for which we obtain $30° 55\frac{1}{2}'$, $56'$, $38° 54'$, respectively.

structural planes (hkl) in order of decreasing spacing (d) with the relative importance of the known forms:

(hkl) ...	(110)	(200)	(001)	($\bar{2}$01)	($\bar{1}$11)	(020)	(310)	(111)
d (Å.) ...	6·66	6·06	4·68	4·66	4·27	3·98	3·60	3·50
Form ...	m (cl.)	a	c (cl.)	x (cl.)	o	b	t	n
(hkl) ...	($\bar{3}$11)	(201)	($\bar{4}$01)	(021)	($\bar{2}$21)	(130)	($\bar{2}$02)	(221)
d (Å.) ...	3·48	3·17	3·15	3·03	3·03	2·59	2·53	2·48
Form ...	—	f	—	r	—	j	(cl.)	p

Among the first sixteen planes in the theoretical list only three are not known as crystal forms or cleavages, the first gap appearing in the ninth place. The remaining six established forms are separated by more numerous gaps farther down the list. All the forms on our crystal appear in the list given, except three new or confirmed forms; in space-group notation these are k(240), l(460), s(420), the relatively complicated indices and small spacings corresponding to the minute size of the faces. From the available drawings m, c, x are clearly the most important forms of augelite, and the order of importance of the remaining forms, so far as can be judged, is tolerably represented by the order of their spacings. There is only one noteworthy exception: (200) takes second place, even with halved spacing, whereas a is generally an unimportant form. On the other hand, one of Dr. Pough's unpublished drawings shows a comparable in size with m and c.

Table I. Augelite: mean measured two-circle angles.

Form.	No. of faces.	ϕ_2.	ρ_2.	Form.	No. of faces.	ϕ_2.	ρ_2.
c(001)	2	67° 35′	89° 58′	*t(310)	1	0° 01′	63° 13′
*−(001) cl.	1	67 31	90 00	r(021)	2	67 46	40 25½
b(010)	1	—	0 00	f(201)	1	38 35	90 04
a(100)	1	0 01	90 01	*−($\bar{1}$01) cl.	1	90 17	90 00
*j(130)	2	0 01½	12 21½	x($\bar{2}$01)	2	112 49½	89 59
*k(120)	2	0 01½	18 12	n(111)	2	50 14	63 54½
*l(230)	2	0 01½	23 35½	*p(221)	1	38 47	51 28
m(110) cl.	2	0 01½	33 21	o($\bar{1}$11)	2	90 21½	57 32½
*s(210)	1	0 01	52 49				

Thus Donnay's law (or actually in this case Bravais' law, since there is no space-group condition beyond that imposed by the lattice) predicts the relative form-development very fairly and explains, for example, why (110) is larger than (100) or (010); why (130) is larger than (120), (310) larger than (210); why (021) is present and (011) is absent, (201) present, (101) absent, and so forth. All these relations are inexplicable according to the old working rule that form importance is directly related to simplicity of indices; but if we write the form symbols

to suit the extinction conditions of the space-group, in this case with $(h+k)$ even, the weaker forms have the more complicated indices and the old rule regains significance as the rule of simplest structural indices.

TABLE II. Augelite—$Al_2PO_4(OH)_3$.

Monoclinic; prismatic—$2/m$

$a : b : c = 1{\cdot}6419 : 1 : 0{\cdot}6354$; $\beta = 112° 26\frac{1}{2}'$
$p_0 : q_0 : r_0 = 0{\cdot}6589 : 1 : 1{\cdot}7027$; $\mu = 67° 33\frac{1}{2}'$
$p_0' = 0{\cdot}4187$, $q_0' = 0{\cdot}6354$, $x_0' = 0{\cdot}4130$

Form.	ϕ.	ρ.	ϕ_2.	ρ_2 = B.	C.	A.
c(001)	90° 00′	22° 26½′	67° 33½′	90° 00′	0° 00′	67° 33½′
b(010)	0 00	90 00	—	0 00	90 00	90 00
a(100)	90 00	90 00	0 00	90 00	67 33½	0 00
j(130)	12 23½	90 00	0 00	12 23½	85 18	77 36½
k(120)	18 14	90 00	0 00	18 14	83 08½	71 46
l(230)	23 43	90 00	0 00	23 43	81 10	66 17
m(110)	33 23	90 00	0 00	33 23	77 52½	56 37
s(210)	52 48½	90 00	0 00	52 48½	72 17½	37 11½
t(310)	63 10	90 00	0 00	63 10	70 05	26 50
g(910)	80 25½	90 00	0 00	80 25½	67 53½	9 34½
r(021)	18 00	53 11½	67 33½	40 24½	49 35½	75 40½
f(201)	90 00	51 21	38 39	90 00	28 54½	38 39
x($\bar{2}$01)	−90 00	23 00	113 00	90 00	45 26½	113 00
n(111)	52 37½	46 18½	50 15	63 58	30 55½	54 56
d(332)	47 31½	54 41	43 51	56 34	40 10½	53 00
p(221)	44 32	60 42½	38 39	51 33½	46 42½	52 17
q(441)	39 24	73 05½	25 35½	42 19½	59 57½	52 36½
o($\bar{1}$11)	−0 31	32 26	90 19½	57 34	38 54	90 16½

Doubtful, or reported without angles: (530), (510), (102), ($\bar{1}$6.0.1), (112), (223), (445), (443), (12.12.5), (661), ($\bar{1}$13), ($\bar{2}$41).

Optics.

From plates and prisms cut in known directions in crystals of augelite from Machacamarca Prior and Spencer (1895) obtained complete optical data which may be stated as follows:

X = b[010]	α 1·5736 (Na)	Positive
Y : c[001] = −56°	β 1·5759	2V = 50° 49′ (meas.), 47° 56′ (calc.)
Z : c[001] = +34°	γ 1·5877	No dispersion observed

A slight ambiguity in the statement of the optical orientation was removed in a later footnote (Spencer, 1898, p. 3).

The optical constants given by Lemmon (1935) agree with those of Spencer within the limits of error; but Lemmon's optical orientation, as given in his figure 2, shows the optical axial plane in the symmetry plane whereas Spencer clearly states that the plane of the optic axes is perpendicular to the plane of symmetry. Since Lemmon does not

comment on this important difference of orientation one may doubt if it was actually observed.

To decide the question of the optical orientation of the Californian augelite short cleavage prisms were examined in temporary mounts on the ordinary stage and in a permanent mount on the universal stage. The optic axial plane was found to lie perpendicular to the symmetry plane, with Z, the acute bisectrix, inclined to the vertical at $34\frac{1}{2}°$ in the obtuse angle β, and 2V 52° measured between sharp optic axis figures on the universal stage. The principal refractive indices were not measured again, in view of the exact agreement in the existing values. These observations confirm Spencer's optical orientation, which is unaffected by the new crystallographic setting. To leave no question regarding the observed orientation fig. 4 (p. 108) is given, showing the optical elements in relation to the crystal forms *a b c m x*, the axis *c*[001], and the outline of the prismatic cleavage form.

Unit cell.

The unit cell of augelite was determined from X-ray photographs with Fe-radiation, using a short (110) cleavage prism turning around the axis of symmetry. The rotation photograph gave the period $b = 7{\cdot}96 \pm 0{\cdot}04$ Å.; Weissenberg resolutions of the zero and first layer-lines gave the spacings $d_{100} = 12{\cdot}11 \pm 0{\cdot}02$ Å., $d_{001} = 4{\cdot}677 \pm 0{\cdot}01$ Å., and the angle (100) : (001) = 67° 43′ ± 20′, corresponding to the geometrical angle ac = 67° $33\frac{1}{2}'$. The quasi-equivalent angle $(\bar{1}00) : (\bar{2}01)$ measured 66° 46′ ± 20′ on the films as compared with the geometrical angle $a'x$ = 67° 00. Thus the pseudo-symmetrical diffractions (00*l*) and $(\overline{2h}.0.h)$ were definitely distinguished. Combining these spacings with the more exact geometrical axial angle we obtain the cell dimensions:

$$a = 13{\cdot}10,\ b = 7{\cdot}96,\ c = 5{\cdot}06 \text{ Å.};\ \beta = 112° 26\tfrac{1}{2}'$$

giving the ratios:

$$a : b : c = 1{\cdot}646 : 1 : 0{\cdot}636$$

as compared with the geometrical ratios:

$$a : b : c = 1{\cdot}6419 : 1 : 0{\cdot}6354$$

With reference to this cell the systematic extinctions are given by the condition: (*hkl*) present only with $(h+k)$ even. The unit cell is therefore base-centred and the space-group is $C_{2h}^3 = C2/m$, if augelite is holohedral. This is precisely the result previously obtained from morphological considerations. Furthermore, it is noteworthy that the adopted

unit cell would have been chosen from purely structural considerations, since a base-centred cell is taken rather than a body-centred cell; and, of the alternative base-centred cells, the one with less oblique axes, which corresponds to the geometrical elements, is preferred.

In regard to the point group symmetry (crystal class) of augelite the evidence is inconclusive. Spencer (1895) noted etch-effects suggesting hemihedrism (domatic class) but obtained no pyroelectric effect by Kundt's method. One of Dr. Pough's unpublished drawings shows different (*hhl*) forms right and left, indicating hemimorphism (sphenoidal class); but we in turn obtained no evidence of polarity of the symmetry

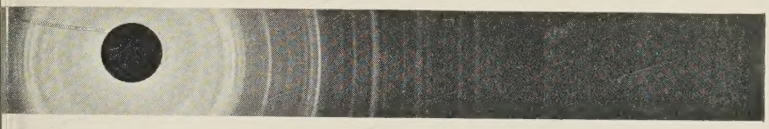

FIG. 5. Augelite: full-size print of an X-ray powder photograph; Cu-$K\alpha$ radiation; 1 mm. on film = $1°\theta$.

axis using the pyroelectric test described by Martin (1931), under conditions that gave a strong reaction with tourmaline. In view of such cases as diamond, sulphur, and topaz, which have yielded holohedral structures in spite of some external evidence of merohedry, and the recognized possibility that etch-figures may have symmetry lower than that of the crystal structure, it seems probable that augelite belongs to the holohedral (prismatic) class.

From the composition $2Al_2O_3.P_2O_5.3H_2O$ confirmed by Prior, and the specific gravity 2·696 measured by Spencer, the unit cell of augelite contains $Al_8P_4O_{16}(OH)_{12} = 4[Al_2PO_4(OH)_3]$, which gives the calculated specific gravity 2·704. This cell content is compatible with the equivalent positions in the holohedral space-group $C2/m$.

Powder pattern.

To aid in the identification of augelite the X-ray powder spectrum, obtained with Cu-radiation (Ni-filter) in a camera with radius $360/4\pi$ mm., is reproduced in fig. 5. In table III are given the visual intensities of the powder rings I(Cu) and the planar spacings d (meas.), with the indices (*hkl*) and the calculated spacings d (calc.), so far as the indexing could be carried with reasonable certainty. The intensities of the corresponding Weissenberg spots I(W) are added for the diffractions that lay in the range of the Weissenberg photographs.

TABLE III. Augelite: X-ray powder spectrum.

I(Cu).	d (meas.).	(hkl).	d (calc.).	I(W).	I(Cu).	d (meas.).
		(001)	4·68	s	w	1·419 Å.
s	4·71 Å.	($\bar{2}$01)	4·66	s	vw	1·385
w	4·30	($\bar{1}$11)	4·27	m	vw	1·354
s	3·99	(020)	3·98	—	w	1·327
		(111)	3·50	s	w	1·268
vs	3·50	($\bar{3}$11)	3·48	s	w	1·268
vs	3·32	(220)	3·33	—	vw	1·238
m	3·16	($\bar{4}$01)	3·15	s	vw	1·211
w	3·03	(400)	3·03	s	vw	1·176
		(221)	2·48	—	vw	1·158
s	2·47	(311)	2·48	m	m	1·134
		($\bar{4}$21)	2·47	—	w	1·089
		($\bar{3}$12)	2·36	m	vw	1·074
vw	2·35	(002)	2·34	s	w	1·065
		(131)	2·19	—	vw	1·008
vw	2·18	($\bar{3}$31)	2·19	—	vw	0·951
vw	2·05	($\bar{5}$12)	2·07	s	vw	0·940
w	1·986	(040)	1·990	—	vw	0·932
		(202)	1·946	s	vw	0·916
m	1·930	($\bar{6}$02)	1·937	vs	vw	0·905
vw	1·890	(240)	1·890	—	vw	0·895
		(331)	1·858	—		
s	1·854	($\bar{5}$31)	1·854	—		
vw	1·705	(312)	1·713	m		
		(241)	1·684	—		
vw	1·676	($\bar{4}$41)	1·682	—		
m	1·586	($\bar{5}$13)	1·591	vs		
vw	1·506	($\bar{8}$21)	1·512	—		
		(151)	1·474	—		
		(441)	1·472	—		
m	1·471	($\bar{3}$51)	1·472	—		
		($\bar{6}$41)	1·470	—		

Summary.

A large well-formed crystal of augelite from the andalusite deposit on White Mountain, Mono Co., California, shows the forms c(001), b(010), a(100), j(130), k(120), l(230), m(110), s(210), t(310), r(021), f(201), x($\bar{2}$01), n(111), p(221), o($\bar{1}$11), with $a : b : c = 1{\cdot}6419 : 1 : 0{\cdot}6354$, $\beta = 112° 26\frac{1}{2}'$ (Spencer, in the structural setting); the forms j k l s t p are new or confirmatory. Cleavages (110), ($\bar{2}$01), also new (001), ($\bar{1}$01). Spencer's optical orientation is confirmed; Z (acute bisectrix): $c = +34\frac{1}{2}°$; $2V = 52°$. The unit cell with a 13·10, b 7·96, c 5·06 Å., $\beta = 112° 26\frac{1}{2}'$, contains $4[Al_2PO_4(OH)_3]$. The space-group obtained from the morphology by Donnay's law, and independently from the X-ray extinctions, is $C_{2h}^3 = C2/m$, accepting the holohedral class indicated by the absence of pyroelectricity (Martin's method). The X-ray powder spectrum is reproduced and partially indexed.

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The determination of ferrous iron in resistant silicates.

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THE determination of ferrous iron in minerals, such as staurolite and kornerupine, which cannot be effectively dissolved by dilute sulphuric and hydrofluoric acids has been made possible on the macro-scale by the work of H. P. Rowledge;[1] the mineral is fused with sodium fluoride and boric oxide at 900° C. in a sealed pyrex glass tube, the fusion cake dissolved in hot dilute sulphuric acid in a current of carbon dioxide, and the solution titrated with potassium permanganate. We have met with no difficulty in applying the method on the macro-scale, but when only small amounts of a mineral are available several difficulties arise, and modifications become necessary.

The air present in the sealed tube of a Rowledge fusion, using the quantities and dimensions he specifies, is already sufficient to oxidize about 3 to 5 mg. of ferrous oxide. But when the weight of the sample is reduced to 10 mg., it is not possible to reduce the dead-space in the tube in proportion; it can hardly be reduced below about $\frac{1}{4}$ c.c. which is sufficient to oxidize 0·3 mg. or 3% FeO and is likely to be more effective in this direction than on the larger scale, since the surface of the fusion is proportionally greater. It is therefore necessary to perform the fusion either in vacuo or with the tube filled with an inert gas. Vacuum fusion is more convenient, and though it was anticipated that the rather thin-walled evacuated tubes would collapse at 900° C., this fear proved unfounded; indeed, if the fused mixture of sodium fluoride and boric oxide was not freshly dried, enough moisture was occasionally present to cause dangerous bulging; thicker-walled tubing than could be handled with the blowpipe at our disposal would be preferable.

A far more serious difficulty was that of dissolving the fusion without oxidation of the ferrous iron; solution in hot dilute sulphuric acid with or without an addition of boric acid was very slow, and it was found very difficult to exclude every trace of air. This might be met by adding a

[1] H. P. Rowledge, Journ. Roy. Soc. Western Australia, 1934, vol. 20 (for 1933–1934), p. 165. [M.A. 6–191.]

known amount of oxidizing agent to the solvent and back-titrating the excess. The oxidizing agent would have to be perfectly stable in hot dilute solution (about 0·01 N or less) for two hours or more, even in presence of hydrofluoric or hydrofluoric and boric acids; potassium permanganate is quite unsuitable, and L. A. Sarver[1] has shown that potassium dichromate is not sufficiently stable in presence of hydrofluoric acid; we have found that an addition of boric acid does not remove this disability. Ceric sulphate seemed very promising; 0·1 N solutions showed no appreciable loss when boiled for 30 minutes with dilute hydrofluoric and sulphuric acids, and the reagent may well be found serviceable for macro-determinations of ferrous iron in non-resistant minerals,[2] but the stability of more dilute solutions is inadequate.

The problem was solved by the use of 0·005 M iodine monochloride in strong hydrochloric acid as an oxidizing solvent; this reagent dissolves the coarsely crushed fusion in about an hour in the cold, and oxidizes the ferrous iron with liberation of iodine: $2Fe^{\cdot\cdot} + 2ICl + 2H^{\cdot} = 2Fe^{\cdot\cdot\cdot} + 2HCl + I_2$. The iodine is re-oxidized with standard potassium iodate to iodine monochloride (which thus plays a purely intermediary part, serving only to prevent air oxidation of ferrous iron) using carbon tetrachloride as indicator. The titration is a very favourable one, as the end point can easily be observed with an accuracy of 0·02 c.c. of 0·0005 M (molar) iodate, equivalent to 0·003 mg. FeO, even in presence of powdered glass (which tends to keep the carbon tetrachloride dispersed).

This method for the solution and titration of the fusion cake is also very convenient and advantageous for a Rowledge fusion on the macro-scale, avoiding any danger of air oxidation, and could be applied directly to olivine and other minerals soluble in cold strong hydrochloric or hydrochloric and hydrofluoric acids.

The modified procedure as adapted for the micro-scale is as follows: a tube of pyrex glass, of 3 mm. bore and as thick-walled as can be worked with the means available, is closed at one end and drawn out into a filling funnel about 3–4 cm. from the closed end; into this tube are weighed 10 mg. of the mineral and 100–150 mg. of Rowledge's flux (2 parts NaF + 1 part B_2O_3, freshly fused and powdered; if it gets damp the tube may be bulged or even burst); the tube is evacuated with a good water pump (< 16 mm. Hg) and sealed under vacuum, the mineral and flux mixed by rotation and shaking, and the tube bedded upright in sand in a tall crucible; after fusion for $\frac{1}{2}$–$\frac{3}{4}$ hour at 900° C. in a muffle or

[1] L. A. Sarver, Journ Amer. Chem. Soc., 1927, vol. 49, p. 1472.

[2] Experiments have been commenced in this connexion.

electric crucible furnace the tube is removed, and laid in a mortar to cool; it is broken with the pestle and as much of the glass as can be freed from the cake removed, the rest being coarsely powdered with the cake. The powdered cake is transferred to a 25 or 50 c.c. flask, preferably glass-stoppered, though a new cork will serve, and dissolved in 5 c.c. or more of a roughly 0·005 M solution of iodine monochloride in 1 : 1 hydrochloric acid[1] and an equal volume of strong hydrochloric acid, rinsing the mortar with the acid (1 c.c. of iodine monochloride will be required for each 1 % of FeO expected, together with a small excess); after about one hour with occasional shaking the cake should be dissolved; from $\frac{1}{2}$ to 1 c.c. of carbon tetrachloride is added and the solution titrated with 0·0005 M potassium iodate ($4Fe^{\cdot\cdot} + IO_3^{\prime} + 6H^{\cdot} + Cl^{\prime} = 4Fe^{\cdot\cdot\cdot} + 3H_2O + ICl$). The titrated solution should not develop any free iodine on standing an hour in the stoppered flask; if it does, the solution of the cake was probably incomplete, and the newly liberated iodine should be titrated; the re-titrated solution is set aside again to make sure that solution is complete.

Using this procedure, 2·30 % FeO was found in a rock which gave 2·15 % by the Pratt method.[2] The rock also contained a trace of sulphide; if this were pyrite, it would not be attacked in the Pratt method, but its sulphur content would reduce ferric iron in the Rowledge method, and would appear as 17 times its weight of FeO. In five kornerupine analyses (this vol. p. 124), duplicate FeO determinations were in good agreement.

[1] 0·18 g. KIO_3 and 0·28 g. KI in 250 c.c. conc. HCl and 250 c.c. water; add a little CCl_4, and if free iodine is present, add very dilute KIO_3 drop by drop till it is removed; if absent, add a few drops of dilute KI till it appears and then remove with KIO_3; store in the dark; if iodine develops on standing, remove with KIO_3.

[2] J. H. Pratt, Amer. Journ. Sci., 1894, ser. 3, vol. 48, p. 149.

Some new data concerning kornerupine and its chemistry.

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[Read June 8, 1939, and January 23, 1941.]

SOME years ago, when working through large parcels of mixed faceted gem-stones in a search for blue spinels[1] of high refractive index, several unusual specimens were encountered, two of which were later identified as kornerupine by Dr. G. F. Claringbull, using X-ray methods. The other stones in these parcels were all quite typical products of the Ceylon gem gravels, consisting mainly of zircons, garnets, and spinels. Since kornerupine is so rare a mineral, and had not previously been reported from Ceylon, it was considered worth while to attempt to place the new occurrence beyond doubt by searching through rough gem gravel imported direct from Ceylon. This was made possible by the kindness of Mr. Hans Van Starrex, who sent a consignment weighing several pounds from the Matale district (Anderson and Payne, 1940).

Rapid sorting was carried out by means of a direct-vision prism spectroscope, with which the characteristic absorption bands of the zircons constituting the bulk of the parcel could at once be discerned in the red and orange regions of the spectrum. Kornerupine, on the other hand, has rather indistinct absorption bands in the blue and violet, as detailed later. By great good fortune a piece of this mineral was encountered only an hour after the search was begun, and a second very similar specimen shortly afterwards. No further kornerupines could be found in the remainder of the parcel, and none at all were found in a subsequent consignment of rough gravel. One could wish for the opportunity to visit Ceylon in order to make a more systematic search and

[1] B. W. Anderson and C. J. Payne, Magnesium-zinc-spinels from Ceylon. Min. Mag., 1937, vol. 24, pp. 547–554.

a more detailed description of the exact localities where the mineral is to be found. The identity of the rough pieces was confirmed by their characteristic pleochroism, flotation in methylene iodide, which they almost match in density, and (when one had been faceted) by optical examination.

In addition to these undoubted Sinhalese kornerupines, other Ceylon-cut specimens of the mineral of rather different type have been encountered on several occasions, which are unusual in being optically pseudo-uniaxial. In colour they are very similar to the stones mentioned above, being brownish-green or dull leaf-green. So far as their appearance goes in the cut state they would pass amongst dealers as chrysoberyl, green zircon, or tourmaline. Though Ceylon is also probably the locality

TABLE I. Optical properties and specific gravities of some gem kornerupines. (B. W. A. and C. J. P.)

Source.	Colour.	Carats.	D^{18}_4.	Ref. ind. (Na) (±0·002).	2V.	Pleochroism.
1. [Madagascar?]	pale sea-green	1·56	3·31 ±0·01	α 1·665 β 1·677 γ 1·678	16½° r>v	distinct
2. Ceylon (rough)	brownish-green	2·15	3·342 ±0·003	—	—	—
3. Ceylon	brownish-green	0·55	3·354 ±0·003	α 1·671 γ 1·684	25° r<v weak	α pale brown β yellow γ dark green
4.* Ceylon	brownish-green	0·91	3·335 ±0·005	α 1·669 β 1·681 γ 1·682	20½° r<v weak	α green β pale brownish-yellow γ pale brownish-green
5. Ceylon	brownish-green	1·00	3·330 ±0·003	—	—	—
6. Ceylon	brownish-green	2·52	3·350 ±0·003	α 1·671 β 1·683 γ 1·684	21°	—
7. [Ceylon?]	brownish-green	9·182	3·325 ±0·005	α 1·666 β 1·678 γ 1·678	5°	α pale brown β dark green γ brown
8.* [Ceylon?]	brownish-green	0·734	3·330 ±0·005	α 1·668 β 1·681 γ 1·681	8°	—
9.* [Ceylon?]	leaf-green	3·50	3·330 ±0·003	α 1·669 β 1·681 γ 1·681	3°	—
10. [Ceylon?]	leaf-green	1·48	3·330 ±0·003	α 1·669 β 1·681 γ 1·681	—	—

* Analysed, see table II.

of these pseudo-uniaxial stones it cannot yet be asserted with complete certainty. The largest known cut kornerupine (9·182 carats) belongs to this type, and was in the British Museum collection (B.M.75946) as idocrase' and later as 'enstatite' before its true identity was realized. Another sizable specimen was purchased from a jeweller in York, and weighed 6·74 carats before part of the stone was slit off for micro-analysis—the re-cut stone weighing 3·50 carats.

The properties of all such specimens so far examined are given in Table I, together with those of a specimen of Malagasy type rescued from a jeweller's junk-box by Major H. J. Beadnell in 1936. The facets of this particular stone are sufficiently flat, and the orientation such, that determinations of β were possible for different wave-lengths by the minimum deviation method, which gave:

	Li (6708).	Na (5893).	Tl (5350).	Ca (4226).	Estimated dispersion.
β	1·6722	1·6764	1·6798	1·6914	B–G 0·018

Specimens 4, 8, and 9 were used for analysis, and correspond to I, II, and III, respectively, in table II. Refractive indices were measured in sodium-light on the Tully, Rayner, and Special Rayner (spinel and diamond) direct-reading refractometers, and densities were determined either by exact suspension in Clerici solution, followed by refractive index measurement of the solution in a hollow prism, or by hydrostatic weighing in ethylene dibromide.[1]

Specimen 7 revealed several absorption bands which were measured with a Beck 'wave-length' spectrometer as follows:

α and γ.	β.
5500 very weak.	5400 very weak.
5030 moderately weak.	5030 moderately weak.
4540 very weak.	4630 very weak.
4440 moderately weak.	4460 strong.
4300 very weak.	4300 very weak.

The measurements are in Ångströms, and on account of the diffuse and weak nature of the bands can only be taken as accurate to about ± 20 A. In none other of the specimens was the absorption spectrum so fully observed, but in all of them the band at 5030 A. could be seen, and this may therefore have some slight diagnostic value.

The inclusions in these kornerupines show certain similarities. The Ceylonese specimens contain 'feathers' made up of small dark crystals arranged in one plane, and many scattered small zircon crystals were seen, in some cases with pleochroic haloes. In nos. 5, 6, and 9 there are numerous short rod-like inclusions parallel to one direction, which are

[1] G. W. Anderson, Gemmologist, London, 1940, vol. 9, p. 141. [M.A. 8 67.]

of similar refractive index to the parent stone, while in nos. 7 and 8 relatively large inclusions of mica were found.

Very shortly after this new occurrence of kornerupine had been established, J. E. de Villiers (1940) published a description and analysis of kornerupine from another new locality, Port Shepstone, Natal; his material was much richer in iron than any previously analysed.

These new occurrences of a mineral, the composition of which was known to be variable but of which only two satisfactory analyses had been made, prompted an optical, X-ray, and chemical study of all available material. We have studied four specimens in detail, three of them cut gems from Ceylon (two of the unusual pseudo-uniaxial type and one optically normal) and one a prismatine from Waldheim, Saxony, kindly supplied by Prof. C. E. Tilley for this work, and have obtained additional data on the Madagascar and Natal material. We were unable to obtain suitable material from the type locality, Fiskernæs, Greenland, for a detailed examination.

Chemical and X-ray data.

The presence of boron in kornerupine was established by A. Lacroix and A. de Gramont (1921), and invalidates the four earlier analyses, while B. Gossner and F. Mussgnug (1928) appear to have overlooked Lacroix's work, and omitted to examine their material for boron; accordingly, only two trustworthy analyses of kornerupine were available when this work was begun, and it soon became clear that even these were imperfect, the ferrous iron determinations being unreliable; fortunately, specimens presented by Lacroix and by de Villiers were available in the British Museum collections, and it was possible to complete these two analyses by new ferrous iron determinations.

The chemical analyses proved unusually difficult; they were necessarily on a micro-scale, as the weights of the three gem specimens were all near 0·1 gram, and the yield of pure prismatine from the Waldheim specimen was of the same order after crushing, hand-picking, and purification with heavy liquids (bromoform and Clerici solution) and the electromagnet.

The most serious difficulties arose from the presence of boron; this had to be determined and it had to be eliminated before the main analysis, both troublesome operations on the micro-scale. For the boron determination, the method of E. Schulek and G. Vastagh[1] was slightly modified: it was found preferable to avoid transferring the sodium carbonate fusion to the distillation flask with water; instead, the fusion was carried out in a micro-crucible, and the crucible, fusion cake, and lid dropped into the flask[2] without any attempt to detach the fusion cake.

[1] E. Schulek and G. Vastagh, Zeits. Anal. Chem., 1931, vol. 84, p. 167; 1932, vol. 87, p. 165.

[2] Some difficulty was experienced in obtaining a distillation apparatus with

Further, it was found that with some specimens of methyl alcohol there is considerable reduction of the sulphuric acid during the second distillation, and the sulphur dioxide evolved may be enough to render the distillate acidic and occasion serious losses; the addition of a little phenol red (which, unlike phenolphthalein, does not fade on standing in strongly alkaline solution) to the alkali in the receiver enables a check to be kept on its alkalinity. Finally, it was not found possible to obtain anything like the precision claimed by Schulek and Vastagh in the titration of small quantities of boric acid with 0·01 N alkali using methyl red and phenolphthalein as indicators; phenolphthalein has too long a transition interval, and even when a reference solution is used the end point is not sharp enough; much greater accuracy was obtained by using a 1 : 1 mixture of bromthymol blue and bromcresol purple as indicator both for the neutralization before addition of mannitol and for the titration proper (the indicator used has a transition range of *p*H 6·0 to 6·8; this is high enough to be fully sensitive to mannito-boric acid and low enough to be insensitive to free boric acid); but even with this an accuracy of $\pm 0{\cdot}10$ c.c. of 0·01 N alkali, equivalent to 0·035 mg. B_2O_3, could not be consistently surpassed in titrations of 10 c.c. of a borax solution containing 40 mg. B_2O_3 per litre.[1] This accuracy corresponds to a probable error of $\pm 0{\cdot}35$ %, or roughly 10 % of the amount present, due to the titration error alone in the determination of the boron in a 10 mg. portion of kornerupine. Further experiments were made with a boron-free rock plus small amounts of added borax, taken through the whole procedure, and showed that the losses in the rest of the process are negligible. The results of the boron determinations (carried out in duplicate, with generally good agreement) are accordingly regarded as reliable within at least $\pm 0{\cdot}5$ %, or about 15–20 % of the amount present.

Owing to the presence of boron, the sodium carbonate fusion for the main analysis had to be treated with methyl alcohol and acid to volatilize the boron before the dehydration of the silica; this raised unexpected difficulties. On the micro-scale, dehydration of the silica by double evaporation with hydrochloric acid, following the usual macro-procedure, has several disadvantages; in particular, the silica from the two evaporations has to be weighed separately, with a double weighing error, and the weighing error in micro-analysis is too large to neglect. An attempt was made to use perchloric acid for the dehydration, after expulsion of the boron with methyl alcohol and hydrochloric acid, but traces of organic matter left from the methyl alcohol reduced the perchloric acid and led to solution of notable amounts of platinum from the crucible. Good results were finally obtained by expelling the boron with methyl alcohol and sulphuric acid, and dehydrating with sulphuric acid. The crude silica carries very considerable amounts of basic sulphates of alumina and iron, and needs thorough ignition for their complete decomposition; if hydrofluoric and sulphuric acids were used for the volatilization of the silica, vigorous ignition would again be needed to decompose the residual sulphates, with risk of loss of weight of the crucible by volatilization of platinum; this is avoided by the use of hydrofluoric and oxalic acids to volatilize the silica. The residue after expulsion of the silica was dissolved by a bisulphate fusion and incorporated with the main solution.

ground joints, made entirely in soda-glass; the resistance glasses commonly employed for this class of apparatus are borosilicate glasses and would not be safe.

[1] The alkali was standardized at a strength of 0·05 N against borax, and then diluted to 0·01 N.

No difficulties were encountered in the main analysis after the determination of the silica. Iron and aluminium were precipitated together by 8-hydroxyquinoline in acetic acid solution at *p*H 5 to 6, and after weighing the precipitate was dissolved in hydrochloric acid and iron precipitated with cupferron.[1] Magnesium was precipitated in the filtrate from the iron and alumina by the addition of further 8-hydroxyquinoline and excess ammonia, and the filtrate from the magnesium was examined for lime. The magnesia-bearing filtrate in one analysis (II) was rendered useless by the failure of a filter-pump, and as no more material was available, magnesia is reported by difference for this specimen.

Alkalis were determined on a separate portion by the Lawrence Smith method in the normal way, except that, since thorough mixing is difficult, instead of using ammonium chloride to form the necessary calcium chloride as flux, a mixture of calcium chloride and calcium carbonate was used, prepared by adding hydrochloric acid to calcium carbonate moistened with alcohol and drying the mixture on the sand-bath.

The determination of ferrous iron proved a particularly difficult problem; as noticed by J. Uhlig (1910) and by C. J. van der Walt (in J. E. de Villiers, 1940), kornerupine is only slowly attacked by hydrofluoric and dilute sulphuric acids. A variety of methods designed to avoid air oxidation during a prolonged acid attack were tried without success, but a modification of the macro-method of H. P. Rowledge was successfully adapted to the micro-scale, and is described fully in a separate communication.[2] With this method, the following results were obtained with the four specimens selected for analysis: I, 4·8 (also 3·1, probably low); II, 7·0; III, 4·7, 5·3; IV, 9·0, 9·3 %. Further, since previous ferrous iron determinations on this mineral must be suspect, specimens from Madagascar (V) and Natal (VI) were examined: V gave 2·8, 3·0 and VI 12·0, 12·3 % FeO; these results agree closely with the values obtained for the total iron (calculated as FeO) by F. Raoult and by C. J. van der Walt, and indicate that in their analyses the iron should all be reported as ferrous; the figures given under V and VI in table II are Raoult's and van der Walt's analyses modified accordingly. Additional confirmation that the iron in the Natal material is wholly ferrous was obtained by a total iron determination made by the following method on 10 mg., which gave 11·8 % total iron as FeO (probably slightly low): the mineral was fused with sodium carbonate, dissolved in 5 c.c. of dilute hydrochloric acid, reduced with metallic zinc and filtered through an Emich filter-stick into 5 c.c. of 0·005 M (molar) iodine monochloride, the flask washed with 8 c.c. of strong hydrochloric acid, and the solution titrated with 0·001 M potassium iodate, using carbon tetrachloride as indicator.

Special tests were made on specimens V and VI for fluorine, with negative results. Spectroscopic examination of specimens I and II show that no constituent present in significant amounts has been overlooked; there are traces of Ca, Mn, Cr, and P.

In order to avoid any assumptions in the calculation of the unit-cell contents X-ray measurements were made on all four analysed specimens,

[1] For this filtration, and for that of the silica and all the filtrations in the Lawrence Smith procedure, the filter-stick devised by Miss C. C. Miller (Journ. Chem. Soc. London, 1939, p. 1962) was found eminently satisfactory.

[2] M. H. Hey, this vol., p. 116.

TABLE II. Chemical analyses of kornerupine. (M. H. H.)

	I.	II.	III.	IV.	V.	VI.
SiO_2	30·5	30·1	29·3	30·5	31·09	29·53
B_2O_3	2·8	3·6	2·5	3·0	3·59	3·5
Al_2O_3	37·6	42·9	40·0	35·8	38·17	40·97
Fe_2O_3	3·3	nil	nil	3·2	nil	nil
FeO	4·8	7·0	5·0	9·1	2·55	12·22
MgO	20·7	[16·4]	21·0	17·6	22·51	10·90
Na_2O	trace	n.d.	0·1	1·6	1·36	0·70
K_2O	trace	n.d.	0·6	trace	0·08	—
Total	99·9*	[100·0]	98·5	100·8	99·96†	99·13§
D_4^{18}	3·335 ±0·005	3·330 ±0·005	3·330 ±0·003	3·370 ±0·010	3·27‡	3·449‖

* Including ignition loss 0·2. † Including CaO 0·51, H_2O 0·10. ‡ This value may be low; a determination on B.M. 1920,424 gave D_4^{18} 3·290 (B. W. A.). § Including MnO 0·08, TiO_2 0·44, P_2O_5 0·12, H_2O 0·67. ‖ J. E. de Villiers's value, corrected for 0·84 % ilmenite and 0·67 % H_2O.

I. Ceylon, normal type. Optics, table I, no. 4.

II. Ceylon, optically pseudo-uniaxial type. Optics, table I, no. 8.

III. Ceylon, optically pseudo-uniaxial type. Optics, table I, no. 9.

IV. 'Prismatine', Waldheim, Saxony. B.M. 1940,21. α 1·675, β and γ 1·687 ±0·004 (Na).

V. Itrongay, Madagascar. Analysis by F. Raoult, in A. Lacroix (1922), corrected in accordance with a new FeO determination on B.M. 1920,424 (a specimen presented by A. Lacroix). α 1·6650, β 1·6766, γ 1·6770, 2V 19½°.

VI. Port Shepstone, Natal. Analysis by C. J. van der Walt, in J. E. de Villiers (1940), corrected in accordance with a new FeO and total iron determination on B.M. 1940,39 (a specimen presented by J. E. de Villiers). α 1·682, β 1·696, γ 1·699, 2V 48°.

TABLE III. Empirical unit-cell contents of kornerupine (Analyses I–VI).

	I.	II.	III.	IV.	V.	VI.
Si	14·9	14·7	14·6	15·0	15·00	15·36
B	2·4	3·0	2·1	2·5	2·98	3·14
Al	21·8	24·8	23·5	20·8	21·68	25·12
$Fe^{'''}$	1·2	—	—	1·2	—	—
$Fe^{''}$	2·0	2·9	2·1	3·8	1·03	5·13
Mg	15·1	[11·9]	15·5	12·9	16·14	8·46
Na	trace	—	0·1	1·5	1·26§	0·70‖
K	trace	—	0·4	—	0·05	—
O	85·0	86·0	85·4	84·2	85·07	87·10
ΣR^*	40·1	39·6	41·6	40·2	40·42	39·44
Si+B	17·3	17·7	16·7	17·5	17·98	18·50
$\Sigma(R, S)$†	57·4	57·3	58·3	57·7	58·40	57·94
F‡	29·40 ±0·29	29·34 ±0·29	29·82 ±0·28	29·56 ±0·34	28·94¶ ±0·4	31·30 ±0·4

* Sum of all atoms except Si, B, and O. † Sum of all atoms except O. ‡ Conversion factor, $VD/1{\cdot}649S$ (see M. H. Hey, Min. Mag., 1939, vol. 25, p. 403). § Also Ca 0·26. ‖ Also Mn 0·03. ¶ This value and all the above cell-contents may be low by 0·7 %, see footnote to table II.

and also the British Museum specimens from Madagascar and Natal (V and VI); no variation in the cell-sides could be detected. The dimensions found, a 13·68±0·04, b 15·95±0·04, c 6·68±0·02 Å., are all smaller than those (a 13·86, b 16·02, c 6·78) found by B. Gossner and F. Mussgnug (1928); while it is possible that the latter are correct for the unusually alkali-rich material examined by them it appears more probable that their results were less accurate than they supposed, and that the unit-cell dimensions of kornerupine do not show appreciable variations. Gossner and Mussgnug found that the unit-cell of kornerupine has one face only centred, namely (001), but did not determine the space-group;[1] Dr. G. F. Claringbull will continue his X-ray work, and expects to determine the space-group at least.

When the empirical unit-cell contents (table III) were calculated from the six available complete analyses and their correlated X-ray and specific gravity measurements, it was clear that the data show regularities which J. E. de Villiers (1940) could not discover for lack of reliable ferrous iron determinations. The average oxygen per unit cell from the data in table III is 85·4, with a mean departure from the mean of 0·6; the corresponding figures for (Si+B) are 17·6 and 0·4; for ΣR, the sum of all atoms other than O, Si, and B, 40·2 and 0·5; and for $\Sigma(R, S)$, the sum of all atoms other than O, 57·8 and 0·4. The tendency of ΣR to 40 and of $\Sigma(R, S)$ to 58, implying (Si+B) 18, are clear, but it is not clear whether the oxygen content approaches 85 or 86; the assessed probable error of 0·9 to 1·2 % in the conversion factor, F, arising from errors in the physical determinations would allow of either.

That the true oxygen content is probably 86 is indicated by a consideration of the probable errors of the chemical analyses. The general effects of analytical errors have been discussed by one of the authors;[2] some account of the extension of these general investigations to a particular case may be useful. The first step is to consider the maximum probable errors in the oxygen content and in ΣR, $\Sigma(R, S)$, and (Si+B). We may probably assume that no single oxide reported in the analysis is in error by more than 1 % (i. e. 1 % of the sum, not of the amount of that oxide present), and there is evidence that no essential constituent present in any significant amount has been overlooked; water has not been determined in analyses II, III, and IV, for lack of material. As water is regarded as an impurity (see below), its only effect is to depress

[1] J. Uhlig (1910) found that the symmetry of etch-figures on prismatine crystals agrees with the requirements of the didigonal equatorial class, D_{2h}.

[2] M. H. Hey, Min. Mag., 1939, vol. 25, p. 402.

the density and hence the observed value of the conversion factor F by $\frac{2}{3}$ % for every 1 % of water present; there is no reason to suppose the 0·2 % H_2O determined in analysis I is seriously low (0·0 to 0·7 % are probable limits in this case), and the high summation of analysis IV suggests that there is little water here; but analysis III has a low sum, and up to 2 % of water might be present and would involve an increase in F of 1·3 %. A consideration of the analytical procedure suggests that any error in B, Si, or Fe is likely to be a loss, and in Mg an excess; Al is probably one of the most accurate values in the analysis, and like Na, is as likely to be high as low. Taking these facts into consideration, and allowing an error up to 1 % in each constituent, it may readily be shown that the true oxygen content is very unlikely to be lower than the 'observed' value by more than 0·3 or higher by more than 0·7 in consequence of analytical errors in constituents other than water; the corresponding figures for ΣR are 1·1 and 0·2, for $\Sigma(R, S)$ 0·5 and 0·6, and for (Si+B) 0·5 and 1·1. Combining these results with the maximum probable errors in F due to non-determination of water and to errors in the physical determinations, the maximum probable errors in cell-contents as determined from the four new analyses may be calculated, with the results shown in table IV. These figures show that the analytical results are compatible with a general formula

$$(Al,Mg,Fe^{\cdot\cdot},Fe^{\cdot\cdot\cdot},Na)_{40}(Si,B)_{18}O_{86},$$

with perhaps a small replacement of Si by Al; this may be expanded to

$$\{(Al,Fe^{\cdot\cdot\cdot})_{20+x+y+z}(Mg,Fe^{\cdot\cdot})_{20-x-2y-z}Na_y\}\{Si_{18-x-z}Al_zB_x\}O_{86}.$$

Any division of the $40\Sigma R$ must await a determination of the space-group. B. Gossner and F. Mussgnug (1928) found that the Bravais

Table IV. Minimum and maximum probable values of the oxygen and other contents of the unit cell of kornerupine.

		I.	II.	III.	IV.
O	minimum	83·9	84·9	84·3	82·9
	maximum	86·5	87·5	86·9	86·0
ΣR	minimum	38·6	38·1	40·1	38·7
	maximum	40·7	40·2	42·2	40·8
(Si+B) ...	minimum	16·6	17·0	16·0	16·8
	maximum	18·6	19·0	18·0	18·8
$\Sigma(R, S)$ ...	minimum	56·3	56·2	57·2	56·5
	maximum	58·6	58·5	59·5	59·0

lattice was the end-centred Γ_o'; if this is correct, then unless there are vacancies in the oxygen lattice, the space-group must be D_{2h}^{19},

the only one having this lattice which possesses the necessary two-fold positions to accommodate a number of oxygen atoms which is not a multiple of four.

It is of interest to consider the five available analyses in which the boron content was overlooked. When an analysis of a boron-bearing mineral is carried out by the usual methods, the presence of boron not being recognized, three things may happen to the boron: a part is usually lost by volatilization during the dehydration of the silica; a part is weighed with, volatilized with, and counted as silica; and the remainder is weighed with and counted as alumina; in other respects the analysis should be of normal accuracy. Now the percentage of boron may be taken as between 2·2 and 3·8 %; its non-estimation will affect the 'apparent' number of oxygen atoms per unit cell, obtained by accepting the analysis as correct, differently according as it is lost, weighed with the alumina, or weighed with the silica, always giving a low 'apparent' value, but lowest when the boron is lost and highest when it is weighed with the silica. A short calculation shows that the true value for the oxygen atoms per unit cell must be between 0·6 and 1·5 higher than the apparent value. Similarly, the effect of the neglect to determine the boron on ΣR, $\Sigma(R, S)$, and (Si + B) may be calculated; the 'apparent' value of ΣR will be the same as the true value if the boron is all weighed as silica, but if it is lost ΣR will be high, and if weighed as alumina higher, by as much as 2·2; (Si + B) and $\Sigma(R, S)$ will be low, the former by from 1·3 to 3·2, the latter by from 0·8 to 1·4.

Applying these considerations to the five incomplete analyses, the atomic contents per 1458 Å^3 were calculated from the analytical figures and densities (table V); these values will be the actual unit-cell contents if the cell-dimensions are really invariable within the accuracy of working, as is probably the case. If the cell-sides found by B. Gossner and F. Mussgnug are adopted for the material they analysed (X), values 3·5 % higher result (Xa).

It is clear that the four early analyses, VII, VIII, IX, and XI are in agreement with the above repeat formula when account is taken of the neglected boron. For if the percentage of boron is between 2·2 and 3·8 %, the 'apparent' number of oxygen atoms per 1458 Å^3 should be between $84{\cdot}5 \pm 1{\cdot}0$ and $85{\cdot}4 \pm 1{\cdot}0$ to comply with the above repeat formula (the $\pm 1{\cdot}0$ represents the probable error in the conversion factor, F, assuming that the densities given in table IV are accurate to $\pm 0{\cdot}01$), while ΣR should be between $42{\cdot}2 \pm 0{\cdot}5$ and $40{\cdot}0 \pm 0{\cdot}5$. The 'observed' values of ΣR suggest that the boron was probably mainly caught with the alumina, which is in accord with the usual experience of analysts; assuming that 3·2 % boron was present and was wholly caught with the alumina, the oxygen contents given under $O_{prob.}$ in table V were calculated; these values are regarded as the results of the most probable interpretation of the analyses, and will be seen to agree well with the proposed repeat formula.

Analysis X (B. Gossner and F. Mussgnug, 1928) offers more difficulties, for if Gossner's cell-dimensions are accepted, the oxygen content is reasonable but unless the boron content is abnormally low (not above 1·3 atoms B per unit cell) the sum (Si + B) will exceed 18, which seems improbable; and if it is assumed that the cell-dimensions of kornerupine do not vary appreciably, as seems more probable, the 'observed' number of oxygen atoms falls below the minimum probable figure of 83·5, and it appears that the bulk of the boron must have been weighed with the silica, which is unusual. Gossner and Mussgnug mention the presence of quartz, tourmaline, mica, and rutile (yet TiO_2 does not appear in the analysis) in their

material in appreciable amounts, and it is possible that their density may be low, but a definite interpretation of their results has not been possible.

TABLE V. Interpretation of some incomplete analyses of kornerupine.

Chemical data and atomic contents per 1458Å^3, indicating the probable fate of the neglected boron.

	VII.	VIII.	IX.	X and Xa.		XI.
SiO_2	30·90	30·89	30·61	33·20		31·35
Al_2O_3	46·79	43·06	42·11	42·36		41·20
FeO*	1·82	6·28	6·50	6·08		2·04
MgO	19·46	15·08	15·23	11·76		23·80
Na_2O	—	2·04	1·85	5·07		0·60
K_2O	—	0·79	0·85	0·83		0·24
H_2O	1·30	1·36	2·08	1·60		0·64
Total	100·27	99·50	99·53†	100·90		99·87
$D_{obs.}$	3·23‡	3·341	3·345	3·28		3·27
$D_{corr.}$§	3·26	3·371	3·383	3·31		3·28
Si	15·0	15·6	15·7	16·3	16·9	15·3
Al	26·7	25·7	25·5	24·5	25·3	23·6
Fe"	0·7	2·7	2·7	2·5	2·6	0·8
Mg	14·0	11·4	11·6	8·6	8·9	17·2
Na	—	2·0	1·8	4·8	4·9	0·6
K	—	0·5	0·6	0·5	0·5	0·2
O	84·8	85·0	85·2	83·2	86·1	84·3
ΣR	41·4	42·3	42·2	40·9	42·3	42·4
Boron mainly ...	caught with Al_2O_3	caught with Al_2O_3	caught with Al_2O_3	caught with SiO_2	caught with Al_2O_3	caught with Al_2O_3
$O_{prob.}$	86·0	86·4	86·5	84·2	87·4	85·6

* Total iron calculated as FeO; summations adjusted accordingly. † Including TiO_2 0·30. ‡ N. V. Ussing (1889) found for Fiskernæs material, D 3·273. § Densities corrected for water (assumed to be an impurity) and in anal. IX for TiO_2 (taken as ilmenite).

VII. Fiskernæs, Greenland. J. Lorenzen, 1884.

VIII. 'Prismatine', Waldheim, Saxony. A. Sauer, 1886.

IX. 'Prismatine', Waldheim, Saxony. J. Uhlig, 1910. α 1·671, β 1·683, γ 1·684, 2V 29°.

X. 'Prismatine', Waldheim, Saxony. B. Gossner and F. Mussgnug, 1928.

Xa. Analysis X, calculated to empirical unit-cell contents, using Gossner and Mussgnug's cell-dimensions.

XI. Betroka, Madagascar. A. Lacroix, 1912 (F. Pisani, analyst). α 1·6613, β 1·6733, γ 1·6742, 2V 20°.

In all the above discussion of the repeat formula of kornerupine, it has been assumed that the water is an unessential impurity. Several workers have regarded it as an essential constituent, since it is only lost at a fairly high temperature. If it is accounted essential, the number of oxygen atoms per unit cell will be increased (the increase will be 0·2x if

x % of water is present), while the number of all other atoms will be decreased (by $1{\cdot}7x$ % for x % of water). The data are not sufficient to decide whether the water is essential or not; if it is the repeat formula must be modified to:

$$\{(Al,Fe^{\cdots})_{20+x+y+z-w}(Mg,Fe^{\cdot\cdot})_{20-x-2y-z+w}Na_y\}$$
$$\{Si_{18-x-z}Al_zB_x\}\{O_{86-w}(OH)_w\}.$$

Summary.

The occurrence of kornerupine in the gem gravels of Ceylon has been established, and specimens are described together with examples of an optically pseudo-uniaxial variety of the mineral. Micro-chemical analyses have been carried out on the new material and on 'prismatine' from Saxony, and previously published analyses are reconsidered in the light of new knowledge. The repeat formula of kornerupine approximates to $Al_{20}Mg_{20}Si_{18}O_{86}$, with considerable replacements of Al and Mg by Fe and Na, and of Si by B and perhaps Al. The boron content is fairly constant, but the iron varies widely. The refractive indices, birefringence, and density increase with the iron content. The methods of chemical analysis are described, and include modifications in the micro-determination of boron.

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The identity of 'eggonite' with sterrettite.

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[Read June 5, 1941.]

DURING the X-ray study of a new phosphate mineral, not yet published, the usual comparison was made with cell-side measurements of related minerals. One of these is 'eggonite', a rare hydrous aluminium phosphate said to occur on silver ores at Felsőbánya, Hungary. Rotation photographs of 'eggonite' are different from those of the new mineral, but yielded dimensions close to those of sterrettite, a new mineral from Fairfield, Utah, described last year by Larsen and Montgomery.[1] These authors generously presented a specimen of sterrettite to the British Museum, and rotation photographs taken in the Mineral Department not only give cell-dimensions close to those published but also identical with those of 'eggonite'. A brief account of this identification is now given not only to justify abandoning the mineral name 'eggonite', but also to place on record a European occurrence of a rare mineral so far described from only one American locality.

'Eggonite' has a strange history. Schrauf[2] first gave the name in 1879 to small, transparent, yellowish crystals resembling baryte which he found on crystallized hemimorphite in compact smithsonite from Altenberg, Moresnet (now in occupied Belgium). His accurate goniometric and optical work on the crystals provided the data tabulated below. Unfortunately his chemical data were few and inaccurate. He identified the mineral as cadmium silicate naming it 'eggonite' (ἔγγονος, grandson) because he believed it occurred as the third generation in the series of natural zinc-cadmium compounds. Having noted the similarity of crystal form he set up 'eggonite' to correspond with baryte and obtained almost the same axial ratios. His two refractive index measurements in monochromatic light using a pair of domes as a refracting prism, yielded, however, values well below those of baryte. Schrauf considered that 'eggonite' only approximated to orthorhombic symmetry and deduced triclinic elements from his goniometric data.

Schrauf must have corresponded with E. S. Dana about the mineral

[1] E. S. Larsen, 3d, and Arthur Montgomery, Amer. Min., 1940, vol. 25, p. 513.

[2] A. Schrauf, Zeits. Kryst. Min., 1879, vol. 3, p. 352.

for in the 1892 edition of the 'System' (p. 905) is found a short entry mentioning as the result of a private communication that the mineral 'eggonite' was after all only baryte and questioning the association. Schrauf may have acknowledged his mistaken chemistry and also cast doubt upon the locality of the crystals, but it is difficult to believe that he is responsible for ignoring his refractive index values and calling 'eggonite' baryte.

Some years later Krenner[1] re-examined Schrauf's original material and discovered that the mineral was really a hydrous aluminium phosphate. He also added to the optical data and remeasured the crystals giving simpler indices to the faces, and deduced orthorhombic symmetry. Krenner identified the crystals as identical with those present on certain specimens of silver ores from Felsőbánya, Hungary. He did not explain, however, why crystals of 'eggonite' had been detached from Felsőbánya specimens and gummed to Altenberg ones, and probably we shall never know whether it was the result of somebody's carelessness or roguery.

Of the two specimens of 'eggonite' in the British Museum collection which were purchased from A. Krantz in 1885, one is a group of intergrown crystals and the other a single crystal about $\frac{1}{2}$ mm. across. Both specimens were found gummed to the matrix of hemimorphite on compact smithsonite and were originally labelled 'Eggonit auf Kieselzinkerz, Altenberg bei Aachen'. The 'eggonite' crystals have a slightly yellowish tint compared with the water-clear crystals of sterrettite. Schrauf's crystal drawing of 'eggonite' (loc. cit., pl. 10, fig. 1, facing p. 352), resembles closely fig. 1*a*, figuring sterrettite in Larsen and Montgomery's paper (loc. cit., p. 515). The single crystal of 'eggonite' referred to above (B.M. 56283) possesses, however, larger faces of the prism form (110) than those figured. X-ray photographs of this crystal confirm Krenner's conclusion that 'eggonite' is orthorhombic. Corresponding photographs of sterrettite are identical in pattern, yielding almost identical cell-edge measurements. The crystal structures of the two minerals must be identical. Since in addition the optical data agree within the limits of error of the methods used, there is a strong probability that the chemical composition of 'eggonite' approximates to that of sterrettite. Krenner applied only qualitative chemical tests to his material and showed that it was a hydrated aluminium phosphate. He suggested on the basis of similarity of axial ratios (if *c* for 'eggonite' is

[1] J. Krenner, posthumous, edited by K. Zimányi, Centralblatt Min., Abt. A, 1929, p. 27. [M.A. 4–332.]

loubled) that the mineral might belong to the strengite-scorodite series nd possess the formula $AlPO_4.2H_2O$.

A more recent suggestion by McConnell[1] that the 'eggonite' might be dentical with metavariscite is disproved by the work of Larsen and Iontgomery, who have found that a powder photograph of sterrettite is ompletely different from those of variscite and metavariscite.

Table of optical and X-ray data for sterrettite, $Al_6(PO_4)_4(OH)_6.5H_2O$.

	Sterrettite.	'Eggonite.'
Optics:		
	$\alpha (= a)$ ... 1·572	$\alpha (= a)$ ... 1·575 (Schrauf)
	$\beta (= b)$ ... 1·590	$\beta (= b)$ ... 1·59 (Krenner)
	$\gamma (= c)$ ... 1·601	$\gamma (= c)$ ... 1·598 (Schrauf)
	2V ... 60°±10°	2V ... 60° 34′ (Krenner)
Axial ratios:		
	$a : b : c$	$a : b : c$
	0·8662 : 1 : 0·5325 (Goniometric)	0·877 : 1 : 0·532 (Schrauf)
	0·872 : 1 : 0·532 (X-ray)	0·8775 : 1 : 0·5369 (Krenner)
Cell-sides:		
	a. *b.* *c.*	*a.* *b.* *c.*
	8·90 10·20 5·43 Å.	8·90 10·24 5·40 Å. (F. A. B.)
Specific gravity (observed):		
	2·36	2·44 (F. A. B.)
Specific gravity (calculated):		
	2·47*	2·46

* Larsen and Montgomery give 493 Å^3 as the cell-volume $8{\cdot}90 \times 10{\cdot}20 \times 5{\cdot}43 =$ 00·3. Their value for sp. gr. 2·45 is in error.

I am indebted to Miss J. M. Sweet for assisting me in the scrutiny of lver ore specimens from Felsőbánya and zinc ores from Altenberg. 'e were unsuccessful in finding any crystals of 'eggonite' on Felsőbánya aterial and therefore Krenner's specimens are the sole evidence for is locality. It would be confusing to retain Schrauf's name 'eggonite' r a mineral he wrongly determined as cadmium silicate and named on count of its supposed association with zinc ores. It may be concluded, erefore, that the newly-named mineral sterrettite from Fairfield, ah, also occurs in Europe and according to Krenner at Felsőbánya, ungary.

[1] D. McConnell, Amer. Min., 1940, vol. 25, p. 723. [M.A. 8–50.]

An anorthite-epidote-garnet-hornfels from Namaqualand, South Africa.

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[Communicated by Prof. Frederick Walker; read November 6, 1941.]

THE present communication deals with a calc-silicate hornfels of uncommon mineralogical and chemical composition. It may be tentatively referred to the deep-seated metamorphism of a marl, and on account of the shortage of analytical data pertaining to metamorphosed sediments of the calcareo-argillaceous type, a detailed investigation of a variety of this group seems justified.

Field Occurrence.

Intercalated bands of anorthite-epidote-garnet-hornfels bordered bilaterally by pyroxene-bearing gneisses occur on the farms Zandfontein, Pella, and Klein Pella in the north-eastern part of the division of Namaqualand, South Africa (cf. geological map[1]). On Klein Pella small exposures also extend intermittingly for approximately 1·5 miles due WNW.–ESE. of the amphibolite koppie situated on the northern boundary of the farm area. The bands exhibit a gentle pinch and swell structure with maximum widths of 15 to 41 inches, and the contact with the host rock is commonly marked by an epidotic fringe $\frac{3}{4}$ inch in thickness. In some cases the anorthite-epidote-garnet-rock is penetrated by parallel lenticles of pure quartz which may attain maximum breadths of 0·8 inch.

The compound xenoliths (Kheis series?) occur in the younger Namaqualand granite-gneiss, which, in the present state of our knowledge, is best regarded as a later phase of the ancient basement granite-gneiss complex of the Union, South-West Africa, and the Rhodesias.[1]

[1] C. B. Coetzee, The petrology of the Goodhouse–Pella area, Namaqualand, South Africa. Trans. Geol. Soc. S. Africa, vol. 44 (for 1941).

Petrography and Mineralogy.

The texture is granoblastic and the absolute grain-size variable. The following data were obtained for the mode on a rather fine-grained homogeneous specimen (fig. 1):

Anorthite	...	57·8	Sphene	...	2·2
Epidote	...	20·2	Apatite	...	0·9
Garnet	...	18·3	Rest	...	0·6

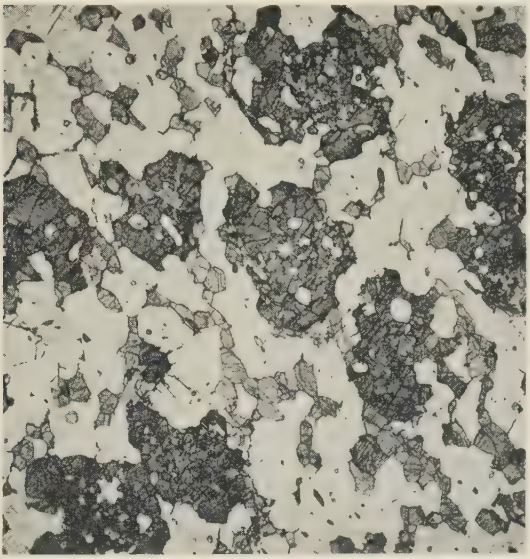

Fig. 1. Anorthite-epidote-garnet-hornfels. The garnet porphyroblasts are traversed by irregular cracks and include anhedra of plagioclase and epidote. The latter is of a lighter colour and its distribution does not suggest a wholesale derivation from the garnet poeciloblasts. Ordinary light. ×16.

Garnet.—Reddish poeciloblastic garnet (average diameters 2·0× 3 mm.) includes pools of basic plagioclase, anhedra of epidote, and crystals of sphene and apatite. The specific gravity and the percentages of FeO and MnO were determined on a 3·3 gm. concentrate, which, in the final stages, was separated by centrifuging in Clerici solution.

n 1·832±0·002	FeO 2·66 %
Sp. gr. 3·78±0·01	MnO 1·33

According to Winchell's graphs[1] the garnet is of the grossular-

[1] A. N. Winchell, Elements of optical mineralogy. New York and London, 3rd ed., 1933, pt. 2, p. 176.

andradite group with andradite : grossular = 6 : 4, and almandine (6·14 %) dominant over spessartine (1·33 %).

Epidote.—A small portion of the epidote (±1 %) arises from the alteration of garnet; the remainder occurs as subhedra (average diameters 0·3×0·2 mm.) whose distribution suggests a primary metamorphic mineral, since there is not the clustering which would be indicative of pseudomorphs after the garnet porphyroblasts.

α 1·732
β 1·755 ±0·002
γ 1·764

$\beta = \gamma$ yellowish-green
α colourless
$\beta \geqslant \gamma > \alpha$

$\gamma - \alpha$ 0·032

$2V_\alpha$ 76°

Clinozoisite 76%, $HCa_2Fe_3Si_3O_{13}$ 24 %.

Plagioclase.—Lime-felspar builds equigranular grains (average diameters 0·5×0·4 mm.) which often have a low twin frequency and the mineral consequently appears as simple crystals.

α 1·570
β 1·578 ±0·002
γ 1·584

Composition, $Ab_{10}An_{90}$.

The remaining constituents comprise greyish sphene ($2V_\gamma$ 31°±3°, α 1·91±0·01) and colourless apatite.

Chemical Analysis and Genesis.

The chemical analysis of the anorthite-epidote-garnet-rock (table 1, column I) compares excellently with the composition of a para-pyroxenite ('grenatite feldspathique') believed to have been produced by the transformation of a marl and described by Lacroix from Madagascar. These para-pyroxenites are part of the crystalline basement of Madagascar and belong to Lacroix's gneissic series. This series is of unknown age, but is thought to have been produced by the general metamorphism (sometimes preceded by mechanical deformation) of schistose rocks.

The sedimentary origin of these rocks is not confirmed by plotting *al*, *alk*, and *c*+*fm* in the standard diagrams devised by Niggli, since the points fall in the eruptive fields corresponding to the particular *c*/*fm* values. But this observation alone, cannot conclusively establish an igneous derivation, because a similar position is assumed by the Niggli values of the Houston marl[1]—a typical sedimentary rock.

The characters suggestive of a sedimentary parentage are: (i) the mode of occurrence, (ii) the chemical composition which is unlike that

[1] Sir John Flett, Thomsonized inclusion from the Blackness sill. Summ. Prog. Geol. Surv. Great Britain, 1934, for 1933, pt. 2, pp. 85–90. [M.A. 6–24.]

of known eruptives and orthogneisses, and (iii) the composition of the garnet, in which connexion Wright[1] has recently shown that 'grossularite and andradite represent over 90 % of the garnet molecules in calcareous contact rocks.' The constitution of the original sediment, calculated by Rosenbusch's formula,[2] indicates a ferriferous marl with approximately 40 % carbonates, and 60 % silicates + quartz + titania (table 1, column III).

TABLE 1.

	I.	II.	III.
SiO_2 ...	41·63	40·04	32·22
TiO_2 ...	0·96	0·39	0·74
Al_2O_3 ...	25·32	27·02	19·60
Fe_2O_3 ...	6·33	2·87	—
FeO ...	1·50	4·75	5·57
MnO ...	0·15	—	0·11
MgO ...	0·28	0·06	0·22
CaO ...	22·06	24·24	17·07
Na_2O ...	0·46	0·29	0·36
K_2O ...	0·17	0·28	0·13
P_2O_5 ...	0·36	0·07	0·28
H_2O+ ...	0·92	0·23	6·66
H_2O- ...	nil	0·05	
CO_2 ...	trace	—	17·10
Total ...	100·14	100·29	100·06

Niggli values.

	I.	II.
al ...	32·6	32·8
fm ...	14·3	12·7
c	51·8	53·8
alk ...	1·2	1·0
c/fm ...	3·62	4·21

I. Anorthite-epidote-garnet-hornfels, Klein Pella. Analyst, W. H. Herdsman.
II. Para-pyroxenite ('grenatite feldspathique'), Ambatonalihala, Madagascar. (A. Lacroix, Minéralogie de Madagascar. Paris, 1922, vol. 2, p. 570.)
III. Composition of original sediment as calculated from analysis I.

By virtue of the three component mineral associations and the absence of micas and potash-felspar, the rock would appear readily adaptable to Goldschmidt's classification of the hornfelses where it falls in class 8, as represented by the anorthite-diopside-grossular triangle.[3] Diopside appears to be proxied by epidote, and this raises the question whether the assemblage, anorthite-epidote-garnet represents a stable equilibrium association which is not accommodated in the classification, and whether in an aqueous environment in the katazone epidote may be generated in lieu of pyroxene.

[1] W. I. Wright, The composition and occurrence of garnets. Amer. Min., 1938, vol. 23, p. 445. [M.A. 7–183.]
[2] H. Rosenbusch, Elemente der Gesteinslehre. Stuttgart, 1910, p. 615.
[3] V. M. Goldschmidt, Die Kontaktmetamorphose im Kristianiagebiet. Skrifter Videnskapsselskapet, I, Mat.-Naturvid. Kl. Kristiania, 1912, vol. 1 (for 1911), p. 192.

The Nature of the Host Rocks.

The anorthite-epidote-garnet-hornfels is always symmetrically enclosed by recrystallized sediments of the lime-silicate type, e.g. pyroxene-epidosite, pyroxene-amphibolite, plagioclase-amphibolite, which attain maximum breadths of over 100 feet and dip from 25° to 40° north. The activity of the surrounding granite is exemplified by the introduction of quartz and potash-felspar into the ultrabasic metamorphics, and sometimes this activity takes the form of lit-par-lit injection, as in the case of the hybrid analysed in table 2, column I.

TABLE 2.

	I.	II.		Norms. I.	Norms. II.	Mode (I).	
SiO_2 ...	65·24	65·69	Q ...	26·82	20·52	Microcline ...	13·2
TiO_2 ...	0·58	0·57	or ...	15·57	16·68	$Ab_{45}An_{55}$ ...	39·3
Al_2O_3 ...	15·41	16·11	ab ...	15·72	31·44	Quartz ...	30·3
Fe_2O_3 ...	1·10	1·76	an ...	25·85	18·90	Amphibole ...	10·1
FeO ...	2·92	2·68	c ...	—	—	Pyroxene ...	4·3
MnO ...	0·04	0·07	di wo ...	4·87	1·04	Rest	2·8
MgO ...	1·56	1·93	di en ...	2·60	0·60		
CaO ...	7·70	4·47	di fs ...	2·11	0·40		
Na_2O ...	1·83	3·74	hy en ...	1·30	4·20		
K_2O ...	2·64	2·78	hy fs ...	1·19	2·24		
P_2O_5 ...	0·18	0·20	mt ...	1·62	2·55		
H_2O+...	0·78	—	il ...	1·22	1·06		
H_2O-...	0·10	—	ap ...	0·34	0·34		
			H_2O ...	0·88	—		
Total	100·08	100·00	Total	100·09	99·97		

I. Migmatized amphibole-pyroxene-gneiss, Klein Pella. Analyst, W. H. Herdsman.
II. Average of 40 granodiorites. (R. A. Daly, Igneous rocks. New York and London, 1933, p. 15.)

From the analysis it is evident that the sediment is converted to a bulk composition corresponding to that of a granodioritic gneiss, and the calcareous nature of the clastic parent is indicated only by a high percentage of lime and a relatively low percentage of soda.

The pyroxene displays all degrees of conversion to hornblende, and as the granite is approached the former shows a tendency to recrystallize as large well-sieved porphyroblasts. A peculiar feature in some of these calc-silicate rocks is the formation of large idioblastic crystals of magnetite (up to 1 inch diameter), but whether this is merely due to the high position of the mineral in the crystalloblastic series, or to the transfusion

of iron from the granite into the sediment there is no evidence to indicate.

The Younger Namaqualand Granite-gneiss.

The affinities of the granite which induced the metamorphism have been investigated in some detail (C. B. Coetzee, loc. cit.): it constitutes a homogeneous coarse to medium grained granite-gneiss which grades into aplitic, but not into granodioritic or more basic differentiates. The average of four chemical analyses and 15 modes are appended in table 3.

TABLE 3.

Average of four chemical analyses.		Norm.		Average of 15 modes.	
SiO_2 ...	72·09	Q	30·06	Quartz ...	34·2
TiO_2 ...	0·41	or	29·47	Microcline ...	30·5
Al_2O_3 ...	13·77	ab ...	26·20	$Ab_{71}An_{29}$ ...	27·3
Fe_2O_3 ...	1·28	an ...	8·90	Biotite ...	5·3
FeO ...	1·27	hy {en ...	1·30	Hornblende ...	0·3
MnO ...	0·01	{fs ...	0·66	Sphene ...	0·5
MgO ...	0·51	mt ...	1·86	Iron-ore ...	1·2
CaO ...	1·97	il ...	0·76	Rest	0·7
Na_2O ...	3·12	ap ...	0·34		
K_2O ...	5·02	H_2O ...	0·53		
P_2O_5 ...	0·09				
H_2O+ ...	0·40	Total ...	100·08		
H_2O- ...	0·13				
Total ...	100·07				

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